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Photosynthesis responses to various soil moisture in leaves of *Wisteria sinensis*

ZHANG Shu-yong[1,2], XIA Jiang-bao[3], ZHOU Ze-fu[1,2*], ZHANG Guang-can[3]

[1]. *Research Institute of Forestry, Chinese Academy of Forestry, Beijing, 100091,P, R, China;*
[2]. *Key Laboratory of Tree Breeding and Cultivation, State Forestry Administration, Beijing, 100091, P, R, China;*
[3]. *Research Center for Eco-Environmental sciences Yellow River Delta, Binzhou University, Binzhou, 256603, Shandong, P, R, China*
[4]. *College of Forestry, Shandong Agricultural University, Tai'an, 271018, Shandong, P, R, China*

Abstract: A study was conducted to determine the fitting soil moisture for the normal growth of two-year-old *W. sinensis* (Sims) Sweets by using gas exchange technique. Remarkable threshold values of net photosynthetic rate (P_n), transpiration rate (T_r) and water use efficiency (WUE*)* were observed in the *W. sinensis* leaves treated by various soil moisture and photosynthetic available radiation (PAR). The fitting soil moisture for maintaining a high level of P_n and WUE was in range of 15.3%–26.5% of volumetric water content (VWC), of which the optimal VWC was 23.3%. Under the condition of fitting soil moisture, the light saturation point of leaves occurred at above 800μmol·m^{-2}·s^{-1}, whereas under the condition of water deficiency (VWC, 11.9% and 8.2%) or oversaturation (VWC, 26.5%), the light saturation point was below 400μmol·m^{-2}·s^{-1}. Moreover, the light response curves suggested that a special point of PAR occurred with the increase in PAR. This special point was considered as the turning point that indicated the functional transition from stomatal limitation to non-stomatal limitation. The turning point was about 600, 1000, 1000 and 400 μmol·m^{-2}·s^{-1}, respectively, at VWC of 28.4%, 15.3%, 11.9% and 8.2% . In conclusion, *W. sinensis* had higher adaptive ability to water stress by regulating itself physiological function.

Keywords: Net photosynthetic rate; Soil moisture; Photosynthetic available radiation; Water use efficiency; *Wisteria sinensis*

Introduction

In recent years, the vegetation restoration and reconstruction have become an ecological focus, because of the deterioration of global ecological environment, such as soil and water erosion, biodiversity loss and global warming etc. Light and soil water content are important ecological factors influencing plant growth and distribution (Cai *et al*. 2004; Cai *et al*. 2005; Mitton *et al*. 1998; Zhang *et al*. 2004). Light has become an outstanding environmental factor with the decrease of ozonosphere (Huang *et al*. 2004; Xu *et al*. 2005; Zhang *et al*. 2004). Meanwhile the contradiction between water shortage and demand is becoming acute in barren mountain area (Cai *et al*. 2004; Honghton *et al*. 1996; Mitton *et al*. 1998; Xiong *et al*. 2005; Zeng *et al*. 2000). Therefore, how the vegetation adapt to soil drought and light stress, caused by global climate change, is one of the problems that people are concerning. Although many studies on the effects of ecological factors on the ecophysiological characteristics and space-time dynamics of crops and non-timber forest are currently available, knowledge of the physiological characteristics especially photosynthetic responses to soil moisture is scant. By now, the researches on liana were mainly focused on its development and utilization (Li *et al*. 2002; Wu *et al*. 2004), such as garden greening, planting technique and officinal value etc., whereas the study on its ecophysiological characteristics was still at a very preliminary stage (Huang *et al*. 2004; Wang *et al*. 2004), especially lacking the data of photosynthetic response in leaves of *Wisteriav sinensis* (Sims) Sweet to various soil moisture and light intensity. The aim of this study is to understand the photosynthetic characteristics in the leaves of *W. sinensis* plants under different soil moisture conditions, which also provides theoretical support for their use in revegetation of drought regions. Our objectives are to (1) investigate the effects of soil water deficits on net photosynthetic rate, transpiration rate and water use efficiency and (2) conform the range of fitting soil water keeping the leaves higher photosynthetic capacity and water use efficiency.

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Biography: ZHANG Shu-yong (1980-), male, PH.D., in Research Institute of Forestry, Chinese Academy of Forestry, Beijing, 100091,P, R, China. E-mail: zhsyong@126.com

*Corresponding author E-mail: zhouzf@caf.ac.cn
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Materials and methods

General situation of investigation area

The experiment was conducted in forestry experiment station, which is located in the southeast of Tai'an city (35°38′-36°33′ N, 116°02′-117°59′ E). It belongs to warm temperate zone with a semi-humid and continental monsoon climate. The average precipitation for multi-year is 741.8 mm, mainly focused on the 7th to 9th month. The annual average temperature is 12.9°C and the

warmest month is July. Frostless season is about 202 days. Brown soil and cinnamon soil are the main soil types.

Materials and water treatment

Eight pieces of two-year-old *W. sinensis* were used as experimental materials. The plants were potted in March, 2005 (the pots were buried chronically in the soil to make the same temperature). The soil water conservation and bulk density, measured by a ring sample, was about 28.1% and 1.17 g/cm^3, respectively. Two months later, the plants were irrigated daily to maintain 28.4% VWC, and the first measurement was carried out. Then irrigation was withheld from the third day and the treatment was lasted for 14 days. The change of VWC was monitored with thetaprobe-MI2X soil moisture probe (AP System, USA). Photosynthetic parameters of the above leaves were measured at 2 day intervals during the stress period, which were corresponding to VWC 26.5%, 23.3%, 20.9%, 18.4%, 15.3%, 11.9%, 8.2%, respectively.

Observation of photosynthetic responses to light intensity

Gas exchange measurements were made during the water stress period, every 2 days between 9:00 and 10:00 h. Every leaf was studied thrice, and then obtained the mean. Six leaves from each treatment were used to measure the net photosynthetic rate (P_n), transpiration rate (T_r), stomatal conductance (G_s) and internal CO_2 concentration (C_i) using a portable photosynthetic system (CIRAS-2, PP System, UK). The photosynthetic light response curve was measured at a range of photosynthetic available radiation (PAR), which was changed every 120s in a sequence of 1600, 1400, 1200, 1000, 800, 600, 400, 250, 200, 150, 100, 50 and 20 μmol·m^{-2}·s^{-1}. Leaf-chamber temperature was controlled under (25±0.5)°C. The following three ratios were calculated: water use efficiency (WUE) = P_n/T_r (Nijs *et al.*, 1997), stomatal limitation value (L_s) =1-C_i/C_a (C_a means atmospheric CO_2 concentration).

Light saturation points (LSP) was calculated by light response curves of photosynthesis (P_n-PAR curve). Light compensation points (LCP), dark respiration rate (R_d) and apparent photosynthetic quantum yield (Φ) were calculated by carrying through linear regression to the beginning parts of response curves (PAR<200 μmol·m^{-2}·s^{-1}).

Results and analyses

Effect of soil moisture on net photosynthetic rate in leaves of *W. sinensis*

The photosynthetic response to light intensity under various soil moistures was shown as Fig. 1. The leaves became light saturated above 800 μmol·m^{-2}·s^{-1} in the range of 15.3%-23.3% VWC. But when VWC was out of this range of soil moisture, leaf LSP was below 400 μmol·m^{-2}·s^{-1}, of which leaf LSP was at the lowest value at the point of 8.2% VWC. The change of quantum yield exhibited a trend similar to photosynthetic rate, which plants at fitting soil moisture used light more efficiently than those at lower or higher soil moisture (Fig. 2). According to the P_n-PAR response curves, remarkable difference in P_n threshold was observed in the leaves treated by various soil moisture. The fitting soil moisture for the potted *W. sinensis* was about 15.3%-23.3%. It was also shown that Φ was about 0.017-0.022, R_d and LCP was about 0.3-0.8 μmol·m^{-2}·s^{-1} and 13-51 μmol·m^{-2}·s^{-1}, respectively, when VWC was in the range of 15.3%-26.5%.

Effect of various soil moisture on transpiration rate in leaves of *W. sinensis*

As shown in Fig. 3, short-term PAR change had very little influence on the T_r. Remarkable difference in T_r was observed in leaves treated by different soil moistures. At water deficiency or oversaturation, T_r was limited below 1.0 mmol·m^{-2}·s^{-1}. The fitting soil moisture, keeping the leaves a high T_r value was about 20.9%-26.5% VWC.

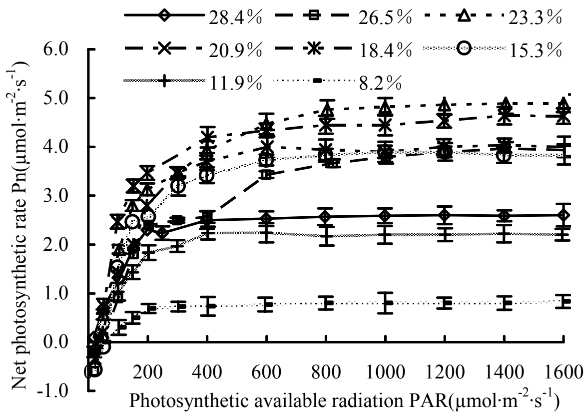

Fig.1 Light responses of photosynthetic rate

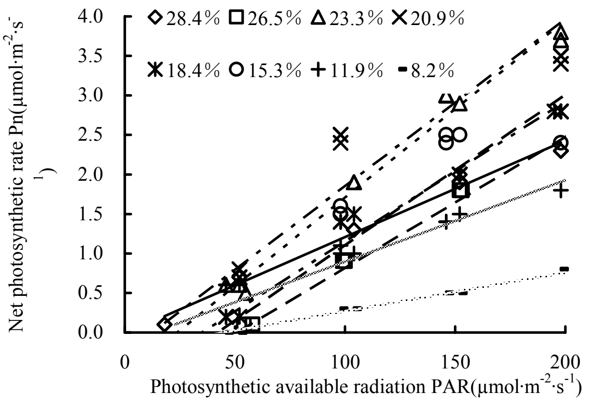

Fig.2 Light responses of photosynthetic rate in low light intensity

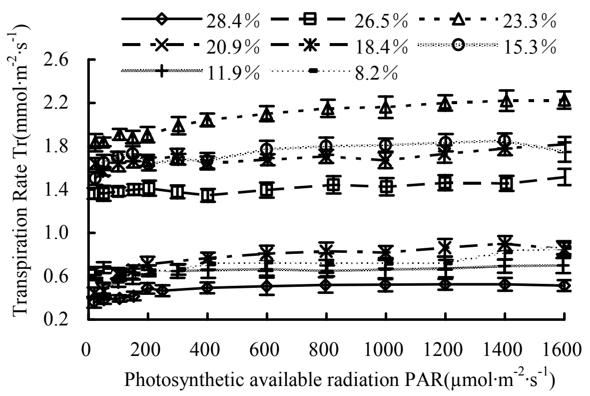

Fig.3 Light responses of transpiration rate

Effects of various soil moisture on intercellular CO_2 concentration, stomata limitation and water use efficiency in leaves of *W. sinensis*

When VWC was about 18.4%-26.5%, parameters took on a significant decrease in C_i and increase in L_s with the increase in PAR. According to the theory of Farquhar and Sharkey, stomatal limitation of photosynthesis occurs when G_s and C_i decrease and L_s increases simultaneously. Therefore it was concluded from above results that stomatal limitation was the primary factor influencing P_n in the leaves stressed. However, when VWC was out of the range (VWC>26.5% or VWC<18.4%), the response process of C_i and L_s were changed obviously, namely with the increase in PAR, C_i increased and L_s decreased gradually at initial stage, whereas PAR was over a special point, C_i decreased and L_s increased. This special point was considered as the turning point that indicated the functional transition from stomatal limitation to non-stomatal limitation. The turning point of PAR was different under various soil moisture, when VWC was about 28.4%, 15.3%, 11.9% and 8.2%, respectively; the point was about 600, 1000, 1000 and 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively. It was inferred from this study that the turning point of PAR was lower under the unfitting soil moistures than that under the fitting condition.

Leaf WUE was determined by the ratio of P_n and T_r. Thus all the factors influencing leaf P_n or T_r would change leaf WUE. When PAR was below 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$, WUE increased obviously with the increase in PAR, otherwise, WUE changed lessly and maintained a high level in a wide range of light intensity. In the range of fitting soil moisture (VWC, 15.3%-26.5%), leaf WUE reached a high level, especially the optimal soil moisture (23.3%). When soil moisture was higher (VWC, 28.4%) or lower (VWC, 11.9%), leaf WUE still maintained a relatively higher level. It was suggested that there was a wide range of soil moisture to maintain the high WUE in leaves of *W. sinensis* Sweet.

Conclusion and discussion

The process of photosynthesis and transpiration was hypersensitive to the environmental change. The leaf photosynthetic response to environment provided the further insights to plant survival and growth. The P_n, T_r and WUE in leaves of *W. sinensis* had the notable threshold value responding to the soil moisture levels and the variation of PAR. Results showed that the fitting soil moisture of the leaves was about 15.3%-26.5% (relative water content (RWC) was about 46.4%-80.3%). This range of soil moisture not only maintained leaf P_n and WUE at high levels, but also restrained water consumption arising from transpiration. When VWC was below 11.9%, severe water stress and high light intensity usually led to the grievous damage to photosynthesis apparatus of the plants and the decrease of leaf P_n and WUE (Fig. 1 and Fig. 6). Thus the minimum soil moisture (VWC) was about 11.9% (RWC was about 36.1%), which maintained *W. sinensis* normal growth. Previous study showed that not all plants had the same water requirements and the fitting soil moisture (VWC) was various among different plants. Usually the fitting soil moisture in agricultural crops was about 60%-80%, Goldspur apple tree 60%-71% (Zhang *et al.* 2004), Black Locust 48%-64%, *Oriental Arborvitae* 41%-52% (Zhang *et al.* 2003; Zhang *et al.* 2001). It is inferred from this study that *W. sinensis* had strong resistance to drought.

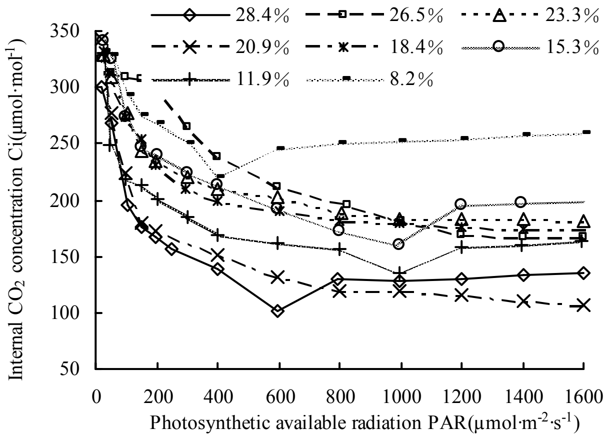

Fig.4 Light responses of internal CO_2 concentration

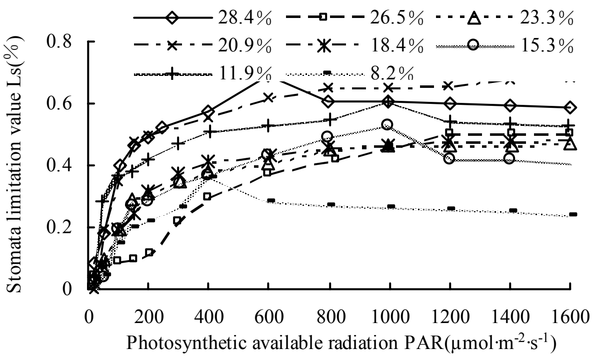

Fig.5 Light responses of stomata limitation value

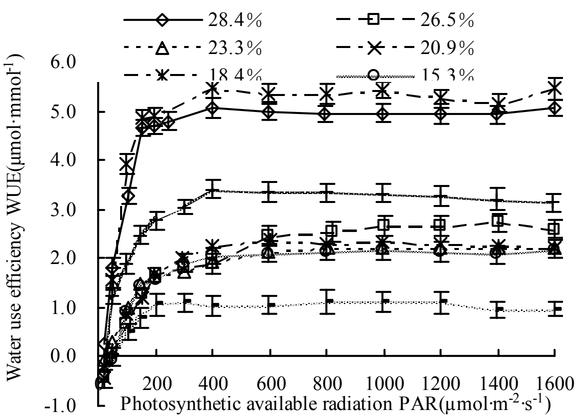

Fig.6 Light responses of water use efficiency

Water stress influenced plant photosynthesis by stomatal regulation, or directly affected the photosynthetic ability of mesophyll cells (Castell *et al*. 1994; Mediavilla *et al*. 2004; Tuzet *et al*. 2003). In the course of water stress, all the responding process of photosynthesis was divided into three phrases on a basis of stomatal limitation and non-stomatal limitation (Chen *et al*. 2004; Zou *et al*. 1998). Stomatal limitation mainly involved locomotion regulation of leaf guard cells, and non-stomatal limitation was correlated with the change of leaf histiocyte (Chen *et al*. 2004). The response of Ls and Ci to light intensity indicated

that non-stomatal limitation did not occur at the leaves treated by the fitting soil moisture, but when VWC was over 26.5% or below 18.4%, with the increase in PAR, the factor limited photosynthesis was transferred gradually from stomatal limitation towards non-stomatal limitation, and light use efficiency and photosynthetic productivity decreased greatly. Results showed that the turning point of PAR was different in the leaves treated by various soil moistures (Fig. 4 and Fig. 5).

Plant LCP and LSP reflected the vegetable photosynthetic requirement to light conditions, and embodied its ability to utilize high light and low light. The vegetation, possessing a low LCP and high LSP, usually had a strong adaptability to light stress, contrarily a low adaptability (Ke *et al.* 2004). It is also shown that in the range of fitting soil moisture, the LCP of *W. sinensis* was about 13-51 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Fig. 2), which was lower than the limited value of typical heliophiles (50-100$\mu mol.m^{-2}.s^{-1}$) (Ke *et al*. 2004). It is suggested that *W. sinensis* can have the shade tolerance to some extent. The leaves became light saturated about 800-1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$, but *W. sinensis* still maintained a high P_n and WUE (Fig. 1 and Fig. 5) in a wider light range (about 1000-1600 $\mu mol \cdot m^{-2} \cdot s^{-1}$).

WUE is not only the comprehensive index for confirming plant physiological function and adaptability to environment, but also the initial index ascertaining plant water supply on its development and growth (Xiong *et al.* 2005). When *W. sinensis* suffered from water shortage or waterlogging (VWC was over 26.5% or below 15.3%), both Pn and Tr fell down to a low level under the high light intensity (Fig. 3), but WUE still kept a high level (Fig. 6).

Based upon all the above discussions, *W. sinensis* had higher adaptive ability to water stress by regulating itself physiological function.

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